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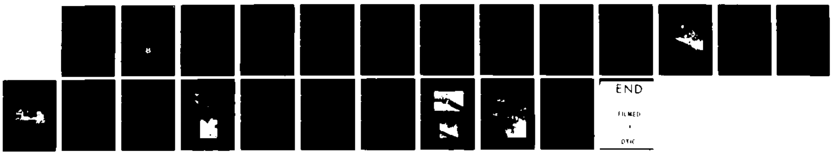

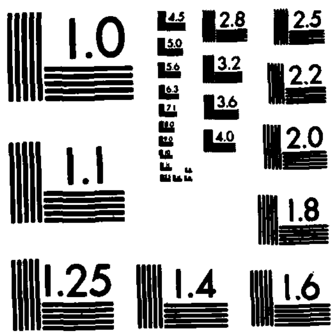

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FIBER OPTIC CABLE VULNERABILITY TEST, WHITE SANDS, NEW MEXICO

By
S. F. LARGE
G. W. STYSKAL

DECEMBER 1982

Prepared for
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Tests were performed at the White Sands Missile Range, New Mexico, to evaluate the response of buried fiber optic cables to the accelerations and stresses developed by an explosive charge. During these tests, observations were made of cable transmissivity characteristics that might be affected by these forces. Transmission bit error rate (BER) measurements were made to determine cable performance changes. Dynamic differential attenuation was measured during detonation to determine any changes in link attenuation (over)

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margins. Permanent changes in cable attenuation profiles were monitored using an optical time domain reflectometer (OTDR).

ACKNOWLEDGMENT

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INTRODUCTION

Strategic and tactical military fiber optic communication systems are vulnerable, in some degree, to explosive blast damage. Long, buried cable plants used in strategic applications are susceptible to damage from hostile attacks such as saturation bombing. A series of tests was recently made at White Sands Missile Range, New Mexico, to observe and evaluate the effects of close proximity explosive forces on buried fiber optic cable. The survivability of fiber and copper cables was compared. Instrumentation was employed to monitor the effects of ground motion, acceleration, and stresses on optical fiber transmission characteristics. This document describes these tests.

SITE AND TEST CONFIGURATION

The test involved the detonation of a 250-kg conventional charge in close proximity to copper and fiber optic cables buried both directly and in protective steel conduits to simulate a buried cable plant. The 250-kg explosive charge equivalent used in this test was generated by 90 lb of liquid nitro-methane, detonated with a prime cord and booster charge.

Five different cables were tested, including two types of fiber optic cable. The three metallic cables were 50-mm and 16-mm coaxial (Heliax) and a composite cable produced by Cableries & Corderies du Hainaut, Dour, Belgium. This composite cable consisted of a 14-gauge twisted pair, a 22-gauge twisted pair, and two coaxial cables. These four conductors were all cabled in a double sheath, one of corrugated steel and the other of lead. It weighed approximately 4 lb/ft. Both optical cahbles were of all dielectric construction. One was a stiff eight-fiber cable approximately 1/2 inch in diameter produced by Opticable, S. A. Mons, Belgium. The other, which was instrumented for this test, was a four-fiber cable produced by ITT, Electro-Optical Product Division, Roanoke, Va.

The fiber optic cables were buried in trenches which were dug in the configuration shown in figure 1. Trenches A, B, and C were placed at distances of 5.5, 3.5, and 2.5 m respectively from the center of the charge casing (ground zero). Trenches B and C were excavated to a depth of 3 m while trench A was 1 m deep.

The bare cable assemblies at each respective depth were laid in the trenches first and covered with 3 to 5 inches of a sand and gravel mixture. The conduit placements consisted of four 10-ft sections screwed together using their threaded matings (see figure 2). The ductile steel conduit had a 5-inch outside diameter with a vinyl clad

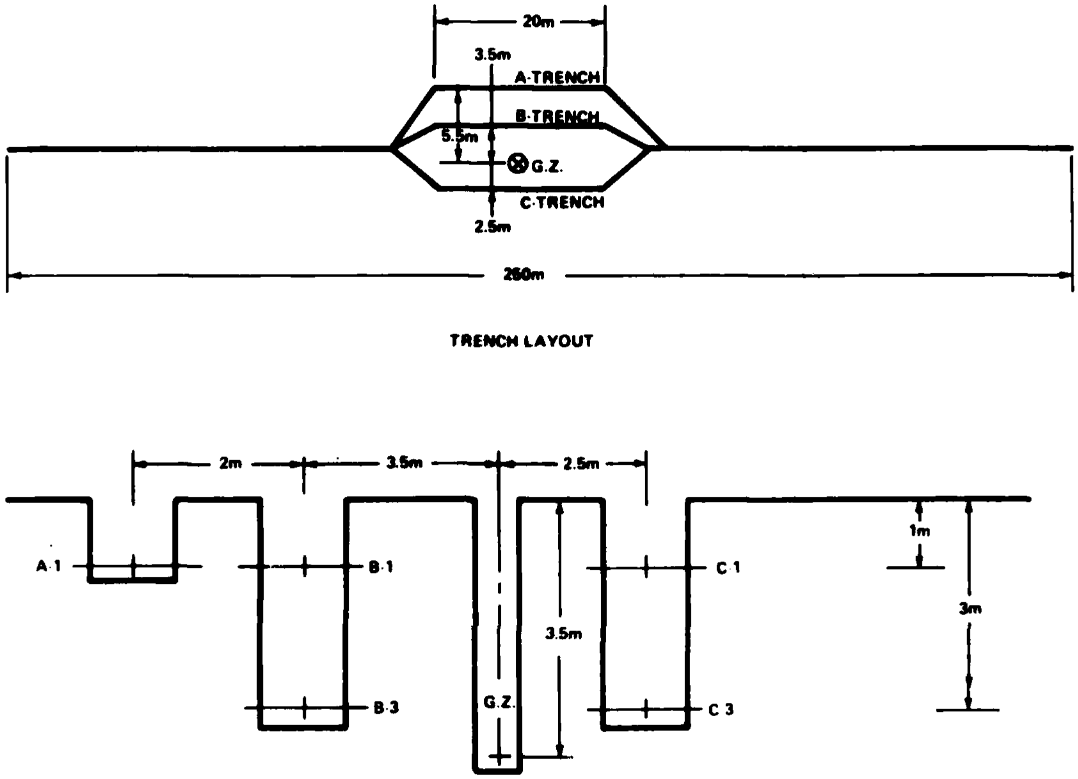


Figure 1. Cable Position Designation

interior. Installing the cables in the conduits required taping the connectors and about 1 ft of cable to the stiffer 50-mm Heliax, and then pushing it through the conduit. The cables in the conduit were placed on top of the sand mixture and covered with 7 to 8 inches more of the same material. The trenches were then backfilled to the next cable depth, and the process was repeated. In previous tests of this nature at the White Sands site, the conduit exhibited a tendency to be violently displaced up and away from the center of the blast. It was speculated that the failure mechanism for some of the bare cables in the previous tests was the moving sections of conduit and not a direct result of the blast. The new orientation of the conduit over the directly buried cable was selected to prevent a moving section of conduit from disrupting a bare cable and invalidating the test results.

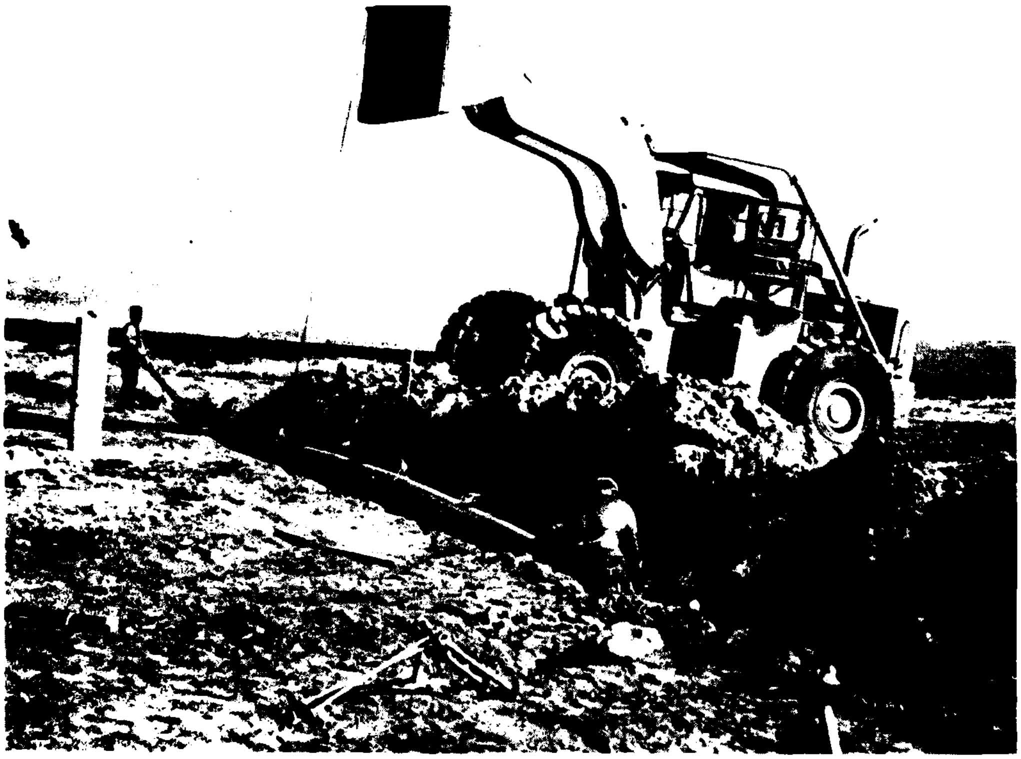
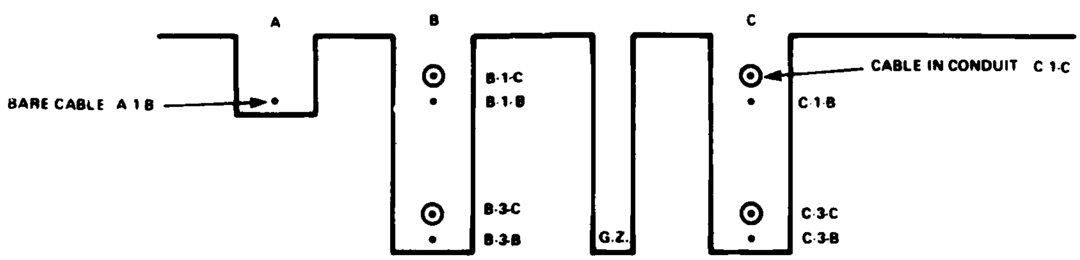


Figure 2. Trenching of Ductile Steel Conduit

Trenches A, B, and C ran parallel at their prescribed depths for a distance of 20 m. To simplify installation, the three trenches converged at each end, and a single 0.5-m-deep trench extended 110 m away from the charge in both directions. The long shallow trenches were used to provide earth-friction anchoring of the 250-m optical cables since no anchoring clamps were to be used which might induce erroneous cable responses. The long cable runs also simulated more closely the response of a long buried cable assembly as might be found in a fixed cable plant. In addition, it was possible to remote the measurement electronics to reduce the possibility of blast damage.

A three-digit mnemonic was used to designate cable position and whether the cable was placed in conduit or directly buried. The first digit represented the trench (A, B, or C). The second digit represented the depth of the buried cable in meters. The third digit designated whether the cable was buried bare (B) or in conduit (C).

This notation is used to reference cables throughout this report. A listing of the seven cable positions and a cross-sectional view of the trenches with cable placement is shown in figure 3.



	A-1-B	B-1-C	B-1-B	B-3-C	B-3-B	C-1-C	C-1-B	C-3-C	C-3-B
MITRE (ITT) OPTICAL CABLE	x	x	x	x	x			x	x
OPTICABLE					x			x	x
50mm COAX		x	x	x	x	x		x	
16mm COAX		x	x	x	x	x		x	
DOUR COMPOSITE			x		x		x		

Figure 3. Cable Placement

TEST INSTRUMENTATION AND PROCEDURE

Test preparations and measurements were conducted from a MITRE van that was specially configured for this test. The van served as a mobile fiber optics laboratory providing workspace and housing equipment used during the test. A photograph of the van at the test site is shown in figure 4.

After the cables were trenched and the trenches completely backfilled and leveled, thorough continuity checks were made using two Wilcom T312 optical attenuation test sets. It was discovered that two connectors were damaged while being pushed through the conduits. These were reconnectorized in the van. At the other end of the 250-m cable, inaccessible to the van, another bad connector was found that was replaced using a small 1750-W generator to power the heat gun used on the heat shrink tubing. This first attempt at field connectorization under harsh desert conditions was successful. Once a satisfactory throughput was achieved on all the cables, a feedthrough connector was used to loop back the signals, using two of the four optical fibers in each cable, for optical time domain reflectometer (OTDR) and bit error rate (BER) measurements. A Laser Precision 9901 OTDR was used to characterize the cables before and after the test to observe changes in the cable "signatures" that resulted from the blast. In addition to this function, the OTDR was an indispensable diagnostic tool, especially in detecting bad connections at the far end. The BER measurements used an HP-3780A bit error rate set transmitting and receiving through an Exxon laser transmitter and an APD receiver. The data format used in the test was a 6-Mb NRZ pseudorandom data sequence. When setting up the BER test, it was discovered that a connector had failed overnight, probably due to the wide (40° to 50°F) overnight temperature excursions. To correct this problem, a truly field expedient reconnectorization was performed without power. A BIC lighter was used on the heat shrink tubing in this successful reconnectorization.

The EPO-TEK SMA connectors used in the test did not perform as well as expected. They were extremely sensitive to rotational and longitudinal adjustment. The OTDR traces were particularly difficult to perform since the signal could drop out altogether by simply tightening the connector into the feedthrough. These problems cannot, however, be blamed solely on the design of the connector. This type of connector was not meant for use in this environment with such rough handling. The epoxy recommended for use is less viscous and requires longer curing which allows greater alignment time. Also, a strength member is meant to be crimped to the connector body for strain relief. This was not possible since single fibers were broken out from a common cable. Considering the misapplication of these connectors, their performance should not be taken to reflect the operational capabilities of that design in its intended environment.

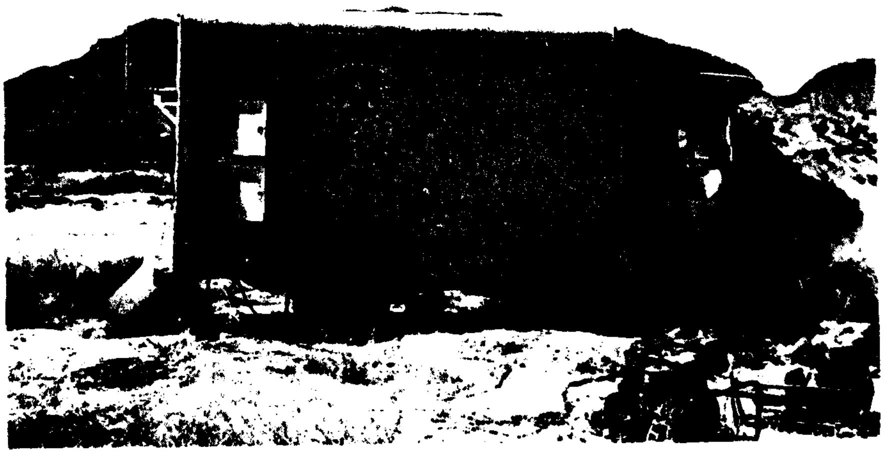


Figure 4. MITRE Fiber Optic Laboratory Van

After completion of preblast OTDR and BER measurements, the dynamic test instrumentation was set up. On the far end of the cables, seven transmitters were connected to one of the four fibers in each of the seven ITT cables. The transmitters consisted of Spectronics SE3352 light emitting diodes transmitting an unmodulated optical signal. The receivers on the near end consisted of Spectronics 50 3478 silicon pin detectors with associated amplifier circuitry. The transmit and receive circuits were powered by 12-V automotive batteries and housed in aluminum cases for protection. The protective cases were left on the surface, and the ends of the cables were marked and stakes were driven at the marks to indicate any cable motion due to insufficient earth-friction anchoring. The receiver outputs were remoted to the van via 800 ft of twisted pair wire. A Honeywell 5600E multichannel recorder and an eight-channel strip chart recorder were used to redundantly record the dynamic measurements. The fire control signal from the charge detonator was an input to the Honeywell recorder to mark the event. A block diagram of the test configuration is shown in figure 5.

On the day of the detonation, final receiver output level checks were made to assure adequate and properly offset signal outputs. It was found that the offset of each receiver had changed since initial calibration. A determination was made that the operational amplifiers were sensitive to severe temperature variations. The final calibration of the receivers occurred just prior to the 11:00 a.m. detonation after the morning chill had burned off.

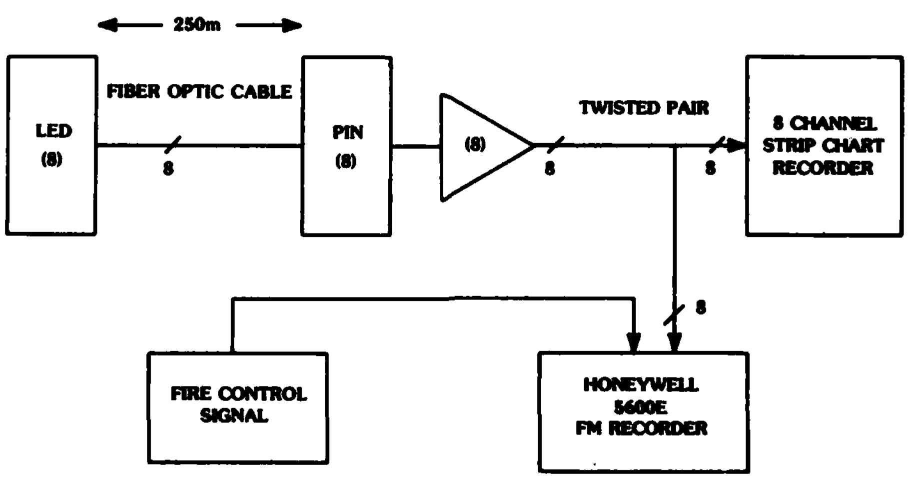


Figure 5. Test Configuration

After the shot, BER measurements were taken using the identical setup and procedures of the preblast measurements. The OTDR was used to recharacterize the cables, and this information was correlated with the physical evidence available at the blast center. The dimensions of the crater were surveyed, and recovery of some cables was attempted to evaluate change and isolate failure mechanisms.

TEST RESULTS

The results of this test proved most interesting. Unlike the first detonation in this three-shot series, the forces of the second blast threw the shallower conduit into disarray within the crater. From observations made after the blast it was found that several threaded conduit joints had "popped" apparently due to stresses that were generated. This failure of the threaded joints is believed to be responsible for the recorded failures of cables in some of the conduit. Stresses generated at positions B-3 and C-3 were estimated, from previous test data, at 4000 and 11,000 psi respectively. Ground accelerations at these positions were estimated to be approximately 5000 g's and greater than 5000 g's respectively. These forces made it easier to understand how the joint may have separated without even stripping the threads (see figures 6 and 7). It is speculated that the male end was compressed more than its surrounding female sleeve allowing it to pull free. The conduit separation put severe stresses, both shear and tensile, on the cables. Differing from the Fort Knox test of July 1981,[1] none of the buried bare cables were exposed by the blast.

The resultant crater from the detonation is illustrated in figure 8. Distances and depths shown are in feet. The ground stress contour lines are estimates based on previous tests. The composition of the soil in the area produces a central mount in all shots in this test series. Conduits in position B-1 and C-1 are displaced with such force that individual 10-ft sections project from the crater at very skew angles. It is also observed that the 110 m of trenching provide excellent earth anchoring for the cables. No cable motion was detected at reference points located at each end of the 150-m cables.

The strip chart recordings provided interesting information regarding the effects of blast dynamics on the cables. The effectiveness of the conduit varied with proximity to the charge. Neither all the cables

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[1]S. F. Large, "Spicing Techniques for Tactical Fiber Optic Systems," Proceedings of the 29th International Wire and Cable Symposium, CORADCOM, Fort Monmouth, N. J., Nov. 18-20, 1980.

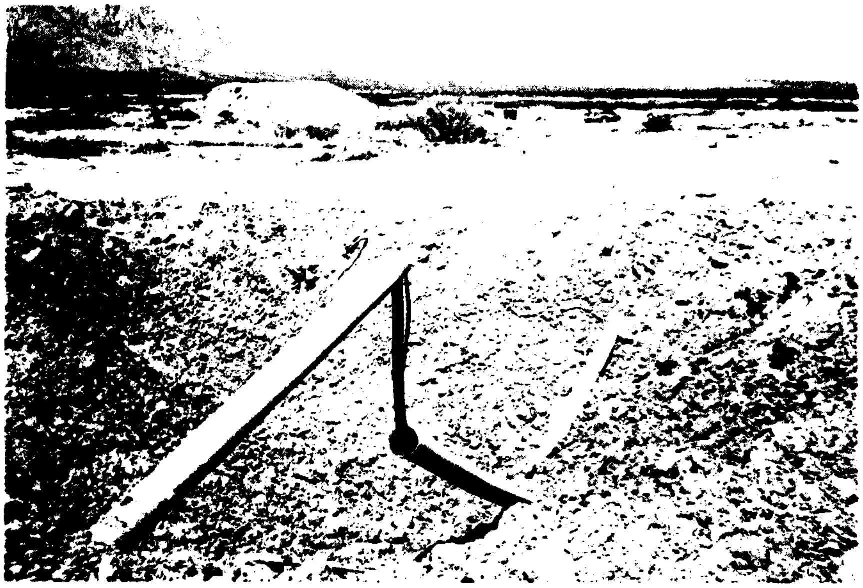

Figure 6. Conduit Separation

Figure 7. Undamaged Conduit Thread

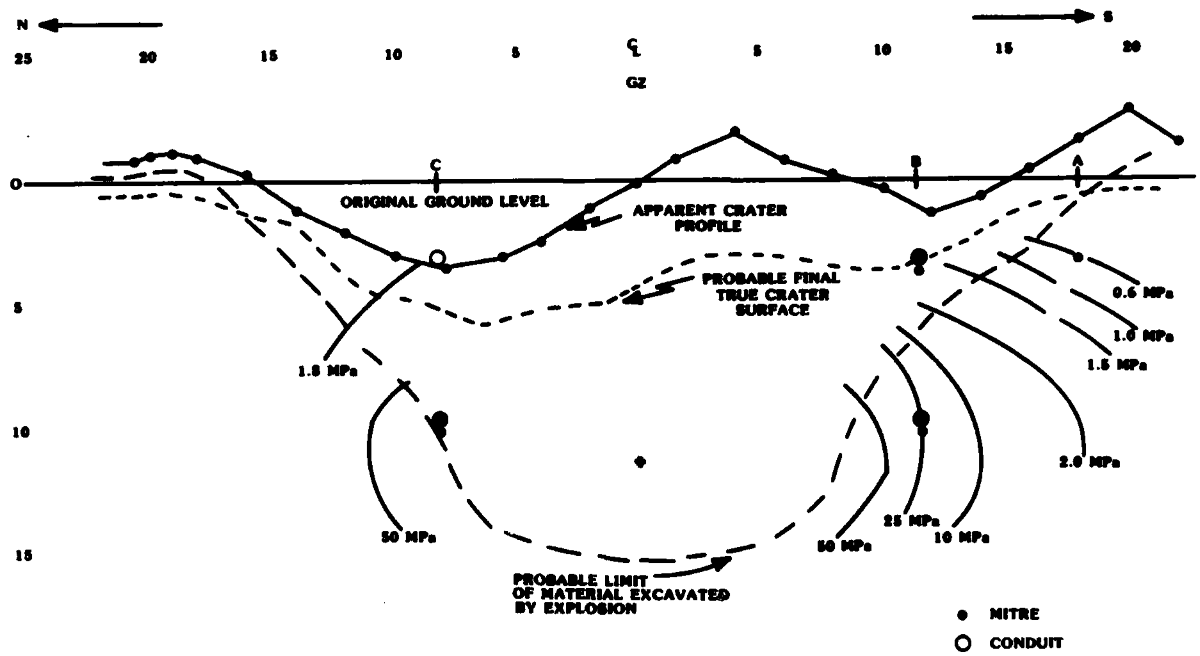

Figure 8. Crater Profile

which survived nor those that failed behaved exactly alike. While bare cables in positions B-3-B and C-3-B failed instantaneously, the protected cable in position C-3-C was damaged after a finite delay. The observed delay may be attributed to the initial separation of a conduit joint and the final break caused by excessive stresses which may have forced the separated conduit to shear the cable. Trench B provided the most valuable information. At the 3-m depth the bare cable was destroyed while the protected cable was unaffected. Position A-1-B shows a transient loss which could be related to both ground motion and crater ejecta fallout. Figure 9 illustrates the five strip chart recording mentioned above.

The CTDR signatures made after the shot provide detailed information on cable failure locations as well as some insight into what form of break occurred. Figure 10 shows the trace for the two cables buried in trench B at 3 m. The cable in the conduit shows no signs of damage over its 250-m length. However, the bare cable is obviously broken at approximately 125 m, the location of the charge. Not only does the break appear, but it is evident from the left-hand end of the trace that the localized drop in signal represents a stressed area of fiber. This condition may be manifested by high tensile forces on the cable.

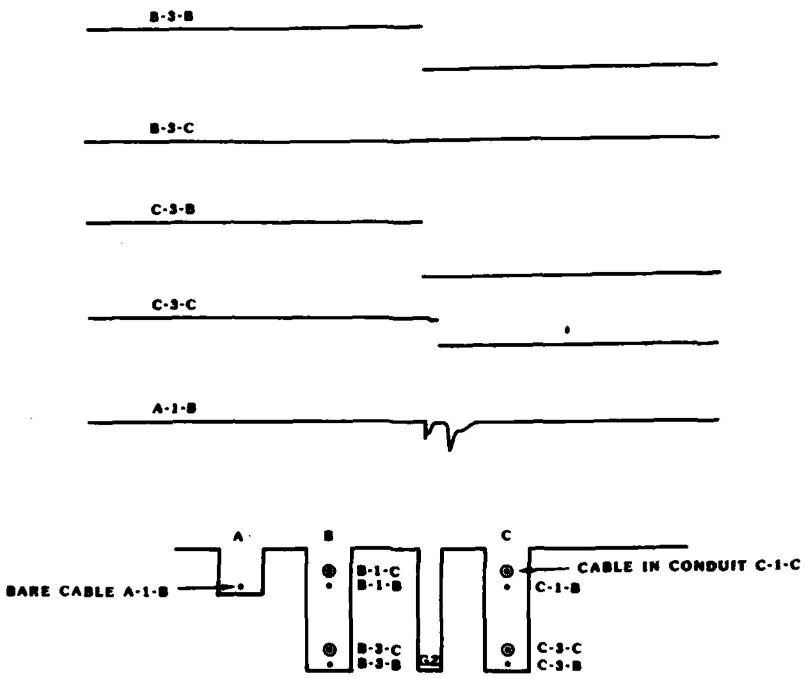

Figure 9. Dynamic Optical Throughput Measurement

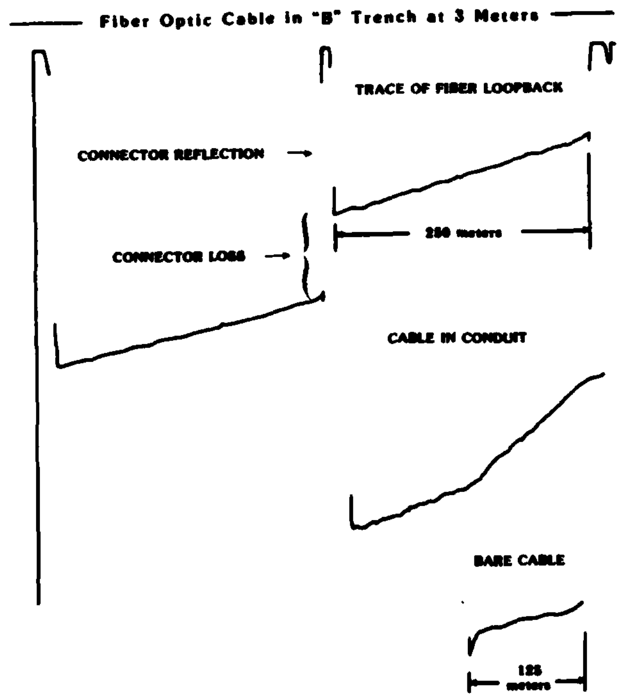

Figure 10. OTDR Trace Before and After Test Shot

A differential attenuation in cable B-1-C was caused by a localized stress point created by the upheaval of the B-1-C conduit. The conduit was disconnected at all three of its joints with the middle two sections forming a triangle (shown in figure 11) sticking up out of the crater about 3 to 4 feet. The vertex of this triangle formed a sharp edge with the end of one section jammed into the opening of the next one. The cables were all somewhat pinched and under a great deal of tension. The combination of the tensile stress and the sharp edge caused the final attenuation. Upon closer examination, it was found that the outer jacket and some of the underlying KEVLAR[R] had been cut rather deeply by the jammed conduit. Despite this severe outer jacket damage, the optical link was still operational even with the induced attenuation.

A position by position comparison between the optical and metallic cables provided a better understanding of the reasons for their survivability. In the B-1-B position, none of the cables appeared affected by the blast. The B-1-C cables were all affected by the conduit's motion. The optical cable suffered an induced attenuation; the 50-mm Heliax showed some pinching 8 ft from one end; the 16-mm Heliax also showed a pinch at 8 ft plus a closure of about 25 percent at 40 ft. The B-3-B position resulted in the destruction of the MITRE cable and probable destruction of the Opticable fibers (data is incomplete at this time). Both Heliax cables survived with no apparent effects, and the Dour composite coaxial showed 50 and 30 percent closures at 32 and 35 ft respectively. In the B-3-B position the 50-mm Heliax showed no effects, while the 16-mm Heliax showed a short at 41 ft. The MITRE optical cable showed no loss possibly due to the larger metallic cables protecting the optical cable from damage. The C-1-C position showed the 5-mm Heliax to be unaffected; however, the 16-mm Heliax had a 25 percent closure at 30 ft. At C-3-B both the Opticable and MITRE cables were destroyed. C-3-C also had the MITRE cable destroyed, however delayed, and the Opticable cable possibly destroyed (again, incomplete data). The 500-mm Heliax was unaffected, and the 16-mm Heliax showed a slight pinch at 8 ft and an open circuit at 15 ft. The reference stakes at the ends of the 250-m cables indicated no cable motion that far from the blast. It appears that connectors or splices would not be affected by the blast unless they were within 40 to 350 ft.

In the final shot of this test series, attempts were made to prevent the threaded conduit joints from separating by welding them together (figure 12). The conduits were placed in similar proximities to the charge, and although greatly displaced by the blast, none of the joints separated (figure 13). Though not dynamically monitored, continuity checks afterward showed that none of the cables had been damaged. This survivability may mean that cables possibly could be placed closer to the charge than previously mentioned.

Figure 11. Vertex Formed by Conduit Separation

Figure 12. Welded Conduit Joint

Figure 13. Survivability of Welded Conduit Joints

CONCLUSIONS

The White Sands tests, as described above, provide useful information regarding fiber optic cable survivability and fiber optic instrumentation. The fact that these cables can be protected when placed as close to the detonation as 3.5 m, and possibly less, is significant. It illustrates their potential use in military communication systems vulnerable to explosive damage due to sabotage or saturation bombing. In addition, these protective techniques allow fiber cables to be used for telemetry applications in explosive test measurements.

The instrumentation used in this test proved to be most valuable in installing, monitoring, and analyzing fiber cables and their response. The portable attenuation test set was easy to use and made quick fiber checkout possible. The OTDR was instrumental in observing the blast effect on the cables. Failure location and type were discernible from the signatures.